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Applicant:	T. Nagai et al.
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Group Art Unit:	Unknown
Examiner:	Unknown
Title:	POSITION DETECTING APPARATUS, POSITION DETECTING METHOD AND POSITION DETECTING PROGRAM

PRELIMINARY AMENDMENT-A

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Washington, DC 20231

Sir:

In connection with the subject new patent application (filed concurrently herewith), please amend the application as follows.

IN THE SPECIFICATION:

Please amend the specification as shown on the attached sheets (including a clean version of the amended paragraphs and a copy of the original paragraphs showing the changes in hand-written markings).

IN THE ABSTRACT:

Please amend Abstract as shown on the attached sheets (including a clean version of the amended drawings and a copy of the drawings showing the changes in hand-written markings).

REMARKS

Upon entry of the present Preliminary Amendment-A the claims in the application are claims 1-10, of which claims 1 and 7 are independent.

The specification and abstract have been amended to overcome minor informalities therein.

Applicant respectfully submits that the amendments are fully supported by the original application.

Favorable consideration is respectfully requested.

Respectfully submitted,

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[0003] However, in addition to it being necessary to provide detailed road map data inside the apparatus, since the detection results of this position detection apparatus contains error in the output values of the distance sensor and azimuth sensor, if position detection according to the output values of the distance sensor and azimuth sensor alone continues for a long period of time, the detection error ends up accumulating resulting in the problem of the detected vehicle position differing greatly from actual vehicle position. In addition, during movement of a humanoid robot that moves by the use of legs indoors in particular, although it is necessary for the robot itself to determine the relative locations of walls and columns, the position detection apparatus of the prior art has the problem of encountering difficulty in autonomous movement since it is difficult to determine relative positional relationships with the surrounding environment.

[0006] According to this aspect of the invention, since the same stationary object is extracted from the images of two consecutive frames as the reference characteristic point, the displacement of this stationary object is determined, and the amount of self-movement is determined from the amount of this displacement, the effect is obtained in which self-position can be detected with high accuracy. In addition, since extraction of the stationary object is performed autonomously, it is not necessary to provide a map and so forth in which the positions of stationary objects are pre-defined, thereby allowing the constitution to be simplified. Moreover, since it is not necessary to provide road map data or other map data, in addition to being able to simplify the constitution, it becomes possible to move to unknown locations, thereby obtaining the effect of being able to eliminate limitations on the range of action of the moving body.

[0008] According to this aspect of the invention, since a position detection device is provided that detects self-position by substituting self-movement control and the observed amount of said reference point into an extended Kalman filter, the effect is obtained in which self-position can be detected more accurately.

[0010] According to this aspect of the invention, since pre-stored object information and extracted characteristic points are compared, and those characteristic points having a high correlation to characteristic points in the pre-stored object information are considered to be known characteristic points that are used as reference characteristic points for calculating position, the effect is obtained in which self-position can be detected more accurately.

[0012] According to this aspect of the invention, since said object information is updated by determining the relative relationship between unknown characteristic points and known characteristic points in an image in which characteristic points considered to be known are present, and storing said unknown characteristic points as known characteristic points, the effect is obtained in which object information can be updated automatically.

[0014] According to this aspect of the invention, since self-position is determined by storing multiple characteristic point groups in an image pre-obtained using said image acquisition device with positions at which said characteristic point groups are obtained, and calculating the correlation between a characteristic point group of a newly obtained

image and pre-stored characteristic point groups, the effect is obtained in which, even in cases in which robot position cannot be obtained geometrically, self-position can be detected based on previous results of position detection.

[0016] According to this aspect of the invention, since the same stationary object is extracted from the images of two consecutive frames as the reference characteristic point, the displacement of this stationary object is determined, and the amount of self-movement is determined from the amount of this displacement, the effect is obtained in which self-position can be detected with high accuracy. In addition, since extraction of the stationary object is performed autonomously, it is not necessary to provide a map and so forth in which the positions of stationary objects are pre-defined, thereby allowing the constitution to be simplified. Moreover, since it is not necessary to provide road map data or other map data, in addition to being able to simplify the constitution, it becomes possible to move to unknown locations, thereby obtaining the effect of being able to eliminate limitations on the range of action of the moving body.

[0018] According to this aspect of the invention, since a position detection device is provided that detects self-position by substituting self-movement control and the observed amount of said reference point into an extended Kalman filter, the effect is obtained in which self-position can be detected more accurately.

[0020] According to this aspect of the invention, since pre-stored object information and extracted characteristic points are compared, and those characteristic points having a high

correlation to characteristic points in the pre-stored object information are considered to be known characteristic points that are used as reference characteristic points for calculating position, the effect is obtained in which self-position can be detected more accurately.

[0022] According to this aspect of the invention, since said object information is updated by determining the relative relationship between unknown characteristic points and known characteristic points in an image in which characteristic points considered to be known are present, and storing said unknown characteristic points as known characteristic points, the effect is obtained in which object information can be updated automatically.

[0024] According to this aspect of the invention, since self-position is determined by storing multiple characteristic point groups in an image pre-obtained using said image acquisition device with positions at which said characteristic point groups are obtained, and calculating the correlation between a characteristic point group of a newly obtained image and pre-stored characteristic point groups, the effect is obtained in which, even in cases in which robot position cannot be obtained geometrically, self-position can be detected based on previous results of position detection.

[0025] The invention according to an eleventh aspect is a position detection program for detecting the position of a moving object, said position detection program comprising performing by computer: image acquisition processing in which an image of the forward field of view of said moving object is acquired, distance image acquisition processing

having the same field of view as said image in which a distance image is acquired simultaneous to acquisition of said image, characteristic point extraction processing in which respective characteristic points are acquired from the images of at least two consecutive frames, and reference characteristic point selection processing in which the amount of displacement of a position between two frames of a characteristic point extracted in said characteristic point extraction processing is calculated based on said distance image, and a reference characteristic point for calculating position according to said amount of displacement is selected.

[0026] According to this aspect of the invention, since the same stationary object is extracted from the images of two consecutive frames as the reference characteristic point, the displacement of this stationary object is determined, and the amount of self-movement is determined from the amount of this displacement, the effect is obtained in which self- position can be detected with high accuracy. In addition, since extraction of the stationary object is performed autonomously, it is not necessary to provide a map and so forth in which the positions of stationary objects are pre-defined, thereby allowing the constitution to be simplified. Moreover, since it is not necessary to provide road map data or other map data, in addition to being able to simplify the constitution, it becomes possible to move to unknown locations, thereby obtaining the effect of being able to eliminate limitations on the range of action of the moving body.

[0027] The invention according to a twelfth aspect is a position detection program for detecting the position of a moving object, said position detection program comprising performing by computer: image acquisition processing in which an image within the

forward field of view of said moving object is acquired, reference point determination processing in which a reference characteristic point to serve as a reference during movement of said moving object is determined based on said image, and position detection processing in which position is detected by substituting self-movement control and the observed amount of said reference point into an extended Kalman filter.

[0028] According to this aspect of the invention, since a position detection device is provided that detects self-position by substituting self-movement control and the observed amount of said reference point into an extended Kalman filter, the effect is obtained in which self-position can be detected more accurately.

[0029] The invention according to a thirteenth aspect is a position detection program for detecting the position of a moving object, said position detection program comprising performing by computer: image acquisition processing in which an image of the forward field of view of said moving object is acquired, distance image acquisition processing having the same field of view as said image in which a distance image is acquired simultaneous to acquisition of said image, characteristic point extraction processing in which respective characteristic points are extracted from obtained images, and reference characteristic point selection processing in which pre-stored object information is compared with extracted characteristic points, and those characteristic points having a high correlation are considered to be known characteristic points that are used as reference characteristic points for calculating position.

[0030] According to this aspect of the invention, since pre-stored object information and extracted characteristic points are compared, and those characteristic points having a high correlation to characteristic points in the pre-stored object information are considered to be known characteristic points that are used as reference characteristic points for calculating position, the effect is obtained in which self-position can be detected more accurately.

[0032] According to this aspect of the invention, since said object information is updated by determining the relative relationship between unknown characteristic points and known characteristic points in an image in which characteristic points considered to be known are present, and storing said unknown characteristic points as known characteristic points, the effect is obtained in which object information can be updated automatically.

[0033] The invention according to a fifteenth aspect is a position detection program for detecting the position of a moving object, said position detection program comprising performing by computer: image acquisition processing in which an image of the forward field of view of said moving object is acquired, characteristic point group extraction processing in which a characteristic point group in said image is extracted, and position detection processing in which position is calculated by correlating and storing multiple characteristic point groups in an image pre-obtained in said image acquisition processing with positions at which said characteristic point groups are obtained, and calculating the

correlation between a characteristic point group of a newly obtained image and pre-stored characteristic point groups.

[0034] According to this aspect of the invention, since self-position is determined by storing multiple characteristic point groups in an image pre-obtained using said image acquisition device with positions at which said characteristic point groups are obtained, and calculating the correlation between a characteristic point group of a newly obtained image and pre-stored characteristic point groups, the effect is obtained in which, even in cases in which robot position cannot be obtained geometrically, self-position can be detected based on previous results of position detection.

DETAILED DESCRIPTION OF THE INVENTION

Best Mode for Carrying Out the Invention

First Embodiment

[0050] The following provides an explanation of a position detection apparatus according to a first embodiment of the present invention with reference to the drawings. Fig. 1 is a block diagram showing the constitution of the present embodiment. Here, the position detection apparatus shown in Fig. 1 is explained in the form of that equipped on an autonomous travel robot that moves indoors. In this drawing, reference symbol 1 represents two cameras that capture an object present in the field of view in the direction of movement during movement by the robot. These cameras are installed at a prescribed interval, and their mutual fields of view are aligned. Reference symbol 2 represents an image storage unit that respectively stores individual frames of images obtained by cameras 1, and is composed of two frames of image memory. Reference symbol 3

represents a distance image formation unit that forms distance images from two frames of images stored in image storage unit 2. Reference symbol 4 represents a distance image storage unit that stores the distance images formed in distance image formation unit 3. Reference symbol 5 represents a characteristic point extraction unit that extracts characteristic points from images stored in image storage unit 2 or distance image storage unit 4. Reference symbol 6 represents a position detection unit that detects self-position based on the results of characteristic point extraction in characteristic point extraction unit 5. Reference symbol 7 represents a movement control unit that controls the movement of the robot by referring to the results of position detection by position detection unit 6.

[0067] Next, position detection unit 6 determines characteristic point distance from the correlating points between each of the extracted reference characteristic points and the distance image stored in distance image storage unit 4, and calculates the amount the robot moved from the time at which the previous image was acquired to the time at which the current image (input image) was acquired based on the amount of movement of that characteristic point and the relative position of the robot (Step S17). When the processing of Step S17 is completed and the position of the robot is determined, the program returns again to Step S1 and repeats the same processing on a characteristic point for which a correlation was previously obtained that has been stored in memory.

[0072] In this manner, by continuously tracking the same stationary object from continuously incorporated images, the displacement of the position of the stationary object can be determined over time, and the amount of self-movement can be determined

each time from the amount of this displacement, thereby enabling self-position to be detected accurately. Although the explanation here has dealt with the example of performing tracking processing with two consecutive images, in order to improve reliability and precision, tracking may be performed by determining the history of movement of a characteristic point from two or more images and extracting stationary objects therefrom.

[0093] Here, an explanation is provided of the processing for calculating robot position in the case of using a Kalman filter. The Kalman filter used here is an extended Kalman filter, and its status equation is shown in Equation (1). Here, if the variables that express the status of the robot are represented with x, y, ϕ and T, and defined as:

$$\vec{P} = \begin{bmatrix} x_t \\ y_t \\ \phi_t \\ T_t \end{bmatrix}$$

then x_t and y_t are the x and y values on the x and y axes, ϕ_t is the angle of rotation about the z axis, and T_t is the distance when moving from time step t to time step (t+1).

$$\begin{bmatrix} x_{t+1} \\ y_{t+1} \\ \phi_{t+1} \\ T_{t+1} \end{bmatrix} = \begin{bmatrix} x_t + \Delta T_t \cos\phi \\ y_t + \Delta T_t \sin\phi \\ \phi_t \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \Delta\phi_t \\ \Delta T_t \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \nu_\phi \\ \upsilon_T \end{bmatrix} \quad \ldots(1)$$

In Equation (1), the second term from the right is the amount of change in distance control at time t from movement control unit 7, while the third term represents the system noise associated with robot control at time t. The coordinate system used here is the same as that of Fig. 4, while the meanings of each of the parameters that express the status of robot position are shown in Fig. 10.

[0094] In addition, Equation (2) is the observation equation of characteristic point a, while Equation (3) is the observation equation of characteristic point b. These equations indicate the relative measured values of characteristic points a and b as viewed from the robot. This measurement equation is produced geometrically based on the coordinate system shown in Fig. 4. The measured amount is expressed with three variables consisting of x, y and θ in the following manner:

[0095] The above Equations (1) through (3) are used in the processing of Steps S25 and S29 shown in Fig. 6. By performing arithmetic operations on these equations each time an image is acquired, robot angle of rotation ϕ_{t+1} and robot position (x_{t+1},y_{t+1}) can be determined. By using this extended Kalman filter, robot position can be detected more

accurately since both system noise and measurement noise are taken into consideration as compared with calculating geometrically as described above. In addition, when using a Kalman filter, although not specifically stated in the judgment of Step S28, the covariance of observed values relative to characteristic points that converges within the Kalman filter can be used as the variance values of those characteristic points.

[0099] Fig. 14 indicates the example of there being 9 positions at which characteristic point groups are stored in memory (M1 through M9), these positions being preset at positions over which the robot is likely to pass. If characteristic point groups extracted from an image captured with a camera facing in the direction of forward direction F→ of the robot from each preset position M1 through M9 are designated as W1 through W9, each position (referred to as a characteristic point acquisition position) M1 through M9 and characteristic point groups W1 through W9 are correlated into respective pairs which are then stored in advance in object data storage unit 8. When the robot is passing over an unknown position, the correlation between the characteristic point groups extracted from the image captured with the camera facing in the direction of forward direction F→ and pre-stored characteristic point groups W1 through W9 is determined, and characteristic point group Wn (where n is any of 1 through 9) having the highest correlation is judged to be the position over which the robot is passing, and the characteristic point acquisition position Mn (where n is any of 1 through 9) that forms a pair with this characteristic point group Wn becomes the self-position. For example, when characteristic point group W4 and a characteristic point group extracted from an image captured with the camera exhibit the closest correlation, position M4 at which this characteristic point group W4 was acquired is determined to be the self-position.

[0104] Next, self-position determination unit 10 selects the characteristic point group for which the sum S of certainty CA determined in Step 48 is largest (Step S52). Self-position is then determined by reading the characteristic point acquisition position that forms a pair with the selected characteristic point group from object data storage unit 8 (Step S53) followed by output of that position as self-position data.

[0106] In this manner, since characteristic point groups within the movable range of a robot and positions at which those characteristic point groups were acquired are pre-stored in the robot, a characteristic point group having a high correlation with characteristic point groups extracted from an image obtained when the robot takes an action is selected from the characteristic point groups stored in memory, and the position at which that selected characteristic point group was acquired is taken to be self-position, so that self-position can be detected easily in cases such as when a robot acts within a predetermined room.

[0111] As has been explained above, according to the present invention, since the same stationary object is extracted from the images of two consecutive frames, the displacement of the stationary object is determined and the amount of self-movement is determined from the amount of this displacement, whereby the present invention offers the advantage of being able to accurately detect self-position. In addition, since extraction of the stationary object can be performed independently, the constitution can be simplified since it is not necessary to provide a map and so forth in which the positions of stationary objects have been defined in advance. Moreover, since it is not necessary to provide a map such as road map data, in addition to it being possible to

simplify the constitution, since the advantage is offered in which it becomes possible to move to an unknown location and eliminate restrictions on the range of action of a moving object, the present invention is particularly suited to a humanoid robot that moves by the use of legs.

[0115] Although there have been described what are the present embodiments of the invention, it will be understood that changes and modifications may be made thereto without departing from the gist, spirit or essence of the invention. The scope of the invention is indicated by the appended claims.

ABSTRACT OF THE DISCLOSURE

A position detection apparatus that detects the position of a moving object, the position detection apparatus comprises a brightness image acquisition device that acquires a brightness image of the forward field of view of the moving object, a distance image acquisition device having the same field of view as the brightness image acquisition device that acquires a distance image simultaneous to acquisition of a brightness image by the brightness image acquisition device, a characteristic point extraction device that extracts respective characteristic points from the brightness images of at least two consecutive frames, and a reference characteristic point selection device that calculates the amount of displacement of a position between two frames of a characteristic point extracted by the characteristic point extraction device based on a distance image, and selects a reference characteristic point for calculating self-position according to said amount of displacement.

detection results of

the apparatus, since this position detection apparatus contains error in the output values of the distance sensor and azimuth sensor, if position detection according to the output values of the distance sensor and azimuth sensor alone continues for a long period of time, the detection error ends up accumulating resulting in the problem of the detected vehicle position differing greatly from actual vehicle position. In addition, during movement of a humanoid robot that moves by the use of legs indoors in particular, although it is necessary for the robot itself to determine the relative locations of walls and columns, the position detection apparatus of the prior art has the problem of encountering difficulty in autonomous movement since it is difficult to determine relative positional relationships with the surrounding environment.

Disclosure of the Invention

In consideration of the circumstances as described above, the object of the present invention is to provide a position detection apparatus, position detection method and position detection program that makes it possible to easily detect self-position using images of the surrounding environment during autonomous movement by a humanoid robot that moves by the use of legs or automobile.

The invention according to a first aspect is a position detection apparatus that detects the position of a moving object, said position detection apparatus being provided with an image acquisition device that acquires an image of the forward field of view of said moving object, a distance image acquisition device having the same field of view as said image acquisition device that acquires a distance image simultaneous to acquisition of an image by said image acquisition device, a characteristic point extraction device that extracts respective characteristic points from the images of at least two consecutive

frames, and a reference characteristic point selection device that calculates the amount of displacement of a position between two frames of a characteristic point extracted by said characteristic point extraction device based on said distance image, and selects a reference characteristic point for calculating self-position according to said amount of displacement.

According to this aspect of the invention, since the same stationary object is extracted from the images of two consecutive frames as the reference characteristic point, the displacement of this stationary object is determined, and the amount of self-movement is determined from the amount of this displacement, the effect is obtained in which self-position can be detected with high accuracy. In addition, since extraction of the stationary object is performed autonomously, it is not necessary to provide a map and so forth in which the positions of stationary objects are pre-defined, thereby allowing the constitution to be simplified. Moreover, since it is not necessary to provide road map data or other map data, in addition to being able to simplify the constitution, it becomes possible to move to unknown locations, thereby obtaining the effect of being able to eliminate limitations on the range of action of the moving body.

The invention according to a second aspect is a position detection apparatus that detects the position of a moving object, said position detection apparatus being provided with an image acquisition device that acquires an image within the forward field of view of said moving object, a reference point determination device that determines a reference characteristic point to serve as a reference during movement of said moving object based on an image obtained from said image acquisition device, and a position detection device that detects position by substituting self-movement control and the observed amount of said reference point into an extended Kalman filter.

According to this aspect of the invention, since a position detection device is provided that

detects self-position by substituting self-movement control and the observed amount of said reference point into an extended Kalman filter, the effect is obtained in which self-position can be detected more accurately.

The invention according to a third aspect is a position detection apparatus that detects the position of a moving object, said position detection apparatus being provided with an image acquisition device that acquires an image of the forward field of view of said moving object, a distance image acquisition device having the same field of view as said image acquisition device that acquires a distance image simultaneous to acquisition of an image by said image acquisition device, a characteristic point extraction device that extracts respective characteristic points from obtained images, and a reference characteristic point selection device that compares pre-stored object information with extracted characteristic points, and considers those characteristic points having a high correlation to be known characteristic points that are used as reference characteristic points for calculating position.

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According to this invention, since pre-stored object information and extracted characteristic points are compared, and those characteristic points having a high

to chacteristic points in the pre-stored object information

correlation are considered to be known characteristic points that are used as reference characteristic points for calculating position, the effect is obtained in which self-position can be detected more accurately.

In the invention according to a fourth aspect, said characteristic point selection device updates said object information by determining the relative relationship between unknown characteristic points and known characteristic points in an image in which characteristic points considered to be known are present, and storing said unknown characteristic points as known characteristic points.

aspect of the

According to this invention, since said object information is updated by

determining the relative relationship between unknown characteristic points and known characteristic points in an image in which characteristic points considered to be known are present, and storing said unknown characteristic points as known characteristic points, the effect is obtained in which object information can be updated automatically.

The invention according to a fifth aspect is a position detection apparatus that detects the position of a moving object, said position detection apparatus being provided with an image acquisition device that acquires an image of the forward field of view of said moving object, a characteristic point group extraction device that extracts a characteristic point group in said image, and a position detection device that calculates position by correlating and storing multiple characteristic point groups in an image pre-obtained with said image acquisition device with positions at which said characteristic point groups are obtained, and calculating the correlation between a characteristic point group of a newly obtained image and pre-stored characteristic point groups.

According to this aspect of the invention, since self-position is ~~calculated~~ determined by storing multiple characteristic point groups in an image pre-obtained ~~with~~ using said image acquisition device with positions at which said characteristic point groups are obtained, and calculating the correlation between a characteristic point group of a newly obtained image and pre-stored characteristic point groups, the effect is obtained in which, even in cases in which robot position cannot be obtained geometrically, self-position can be detected based on previous results of position detection.

The invention according to a sixth aspect is a position detection method that detects the position of a moving object, said position detection method having an image acquisition process in which an image of the forward field of view of said moving object is acquired, a distance image acquisition process having the same field of view as said

image in which a distance image is acquired simultaneous to acquisition of said image, a characteristic point extraction process in which respective characteristic points are acquired from the images of at least two consecutive frames, and a reference characteristic point selection process in which the amount of displacement of a position between two frames of a characteristic point extracted in said characteristic point extraction process is calculated based on said distance image, and a reference characteristic point for calculating position according to said amount of displacement is selected.

According to this aspect of the invention, since the same stationary object is extracted from the images of two consecutive frames as the reference characteristic point, the displacement of this stationary object is determined, and the amount of self-movement is determined from the amount of this displacement, the effect is obtained in which self-position can be detected with high accuracy. In addition, since extraction of the stationary object is performed autonomously, it is not necessary to provide a map and so forth in which the positions of stationary objects are pre-defined, thereby allowing the constitution to be simplified. Moreover, since it is not necessary to provide road map data or other map data, in addition to being able to simplify the constitution, it becomes possible to move to unknown locations, thereby obtaining the effect of being able to eliminate limitations on the range of action of the moving body.

The invention according to a seventh aspect is a position detection method that detects the position of a moving object, said position detection method having an image acquisition process in which an image within the forward field of view of said moving object is acquired, a reference point determination process in which a reference characteristic point to serve as a reference during movement of said moving object is determined based on said image, and a position detection process in which position is

detected by substituting self-movement control and the observed amount of said reference point into an extended Kalman filter.

According to this aspect of the invention, since a position detection device is provided that detects self-position by substituting self-movement control and the observed amount of said reference point into an extended Kalman filter, the effect is obtained in which self-position can be detected more accurately.

The invention according to an eighth aspect is a position detection method that detects the position of a moving object, said position detection method having an image acquisition process in which an image of the forward field of view of said moving object is acquired, a distance image acquisition process having the same field of view as said image in which a distance image is acquired simultaneous to acquisition of said image, a characteristic point extraction process in which respective characteristic points are extracted from obtained images, and a reference characteristic point selection process in which pre-stored object information is compared with extracted characteristic points, and those characteristic points having a high correlation are considered to be known characteristic points that are used as reference characteristic points for calculating position.

According to this aspect of the invention, since pre-stored object information and extracted characteristic points are compared, and those characteristic points having a high correlation (to characteristic points in the pre-stored object information) are considered to be known characteristic points that are used as reference characteristic points for calculating position, the effect is obtained in which self-position can be detected more accurately.

In the invention according to a ninth aspect, the above characteristic point selection process updates said object information by determining the relative relationship between unknown characteristic points and known characteristic points in an image in

which characteristic points considered to be known are present, and storing said unknown characteristic points as known characteristic points.

According to this aspect of the invention, since said object information is updated by determining the relative relationship between unknown characteristic points and known characteristic points in an image in which characteristic points considered to be known are present, and storing said unknown characteristic points as known characteristic points, the effect is obtained in which object information can be updated automatically.

The invention according to a tenth aspect is a position detection method that detects the position of a moving object, said position detection method having an image acquisition process in which an image of the forward field of view of said moving object is acquired, a characteristic point group extraction process in which a characteristic point group in said image is extracted, and a position detection process in which position is calculated by correlating and storing multiple characteristic point groups in an image pre-obtained in said image acquisition process with positions at which said characteristic point groups are obtained, and calculating the correlation between a characteristic point group of a newly obtained image and pre-stored characteristic point groups.

According to this aspect of the invention, since self-position is calculated determined by storing multiple characteristic point groups in an image pre-obtained with using said image acquisition device with positions at which said characteristic point groups are obtained, and calculating the correlation between a characteristic point group of a newly obtained image and pre-stored characteristic point groups, the effect is obtained in which, even in cases in which robot position cannot be obtained geometrically, self-position can be detected based on previous results of position detection.

The invention according to an eleventh aspect is a position detection program for detecting the position of a moving object, said position detection program comprising

performing by computer image acquisition processing in which an image of the forward field of view of said moving object is acquired, distance image acquisition processing having the same field of view as said image in which a distance image is acquired simultaneous to acquisition of said image, characteristic point extraction processing in which respective characteristic points are acquired from the images of at least two consecutive frames, and reference characteristic point selection processing in which the amount of displacement of a position between two frames of a characteristic point extracted in said characteristic point extraction processing is calculated based on said distance image, and a reference characteristic point for calculating position according to said amount of displacement is selected.

According to th~~is~~ aspect of the invention, since the same stationary object is extracted from the images of two consecutive frames, so the reference characteristic point ~~the displacement of this stationary object~~ is determined, and the amount of self-movement is determined from the amount of this displacement, the effect is obtained in which self- position can be detected with high accuracy. In addition, since extraction of the stationary object is performed autonomously, it is not necessary to provide a map and so forth in which the positions of stationary objects are pre-defined, thereby allowing the constitution to be simplified. Moreover, since it is not necessary to provide road map data or other map data, in addition to being able to simplify the constitution, it becomes possible to move to unknown locations, thereby obtaining the effect of being able to eliminate limitations on the range of action of the moving body.

The invention according to a twelfth aspect is a position detection program for detecting the position of a moving object, said position detection program comprising performing by computer image acquisition processing in which an image within the forward field of view of said moving object is acquired, reference point determination

processing in which a reference characteristic point to serve as a reference during movement of said moving object is determined based on said image, and position detection processing in which position is detected by substituting self-movement control and the observed amount of said reference point into an extended Kalman filter.

According to this aspect of the invention, since a position detection device is provided that detects self-position by substituting self-movement control and the observed amount of said reference point into an extended Kalman filter, the effect is obtained in which self-position can be detected more accurately.

The invention according to a thirteenth aspect is a position detection program for detecting the position of a moving object, said position detection program comprising performing by computer, image acquisition processing in which an image of the forward field of view of said moving object is acquired, distance image acquisition processing having the same field of view as said image in which a distance image is acquired simultaneous to acquisition of said image, characteristic point extraction processing in which respective characteristic points are extracted from obtained images, and reference characteristic point selection processing in which pre-stored object information is compared with extracted characteristic points, and those characteristic points having a high correlation are considered to be known characteristic points that are used as reference characteristic points for calculating position.

According to this aspect of the invention, since pre-stored object information and extracted characteristic points are compared, and those characteristic points having a high correlation to characteristic points in the pre-stored object information are considered to be known characteristic points that are used as reference characteristic points for calculating position, the effect is obtained in which self-position can be detected more accurately.

In the invention according to a fourteenth aspect, the above characteristic point

selection processing updates said object information by determining the relative relationship between unknown characteristic points and known characteristic points in an image in which characteristic points considered to be known are present, and storing said unknown characteristic points as known characteristic points.

According to this aspect of the invention, since said object information is updated by determining the relative relationship between unknown characteristic points and known characteristic points in an image in which characteristic points considered to be known are present, and storing said unknown characteristic points as known characteristic points, the effect is obtained in which object information can be updated automatically.

The invention according to a fifteenth aspect is a position detection program for detecting the position of a moving object, said position detection program comprising performing by computer image acquisition processing in which an image of the forward field of view of said moving object is acquired, characteristic point group extraction processing in which a characteristic point group in said image is extracted, and position detection processing in which position is calculated by correlating and storing multiple characteristic point groups in an image pre-obtained in said image acquisition processing with positions at which said characteristic point groups are obtained, and calculating the correlation between a characteristic point group of a newly obtained image and pre-stored characteristic point groups.

According to this aspect of the invention, since self-position is ~~calculated~~ determined by storing multiple characteristic point groups in an image pre-obtained ~~with~~ using said image acquisition device with positions at which said characteristic point groups are obtained, and calculating the correlation between a characteristic point group of a newly obtained image and pre-stored characteristic point groups, the effect is obtained in which, even in cases in which robot position cannot be obtained geometrically, self-position can be detected

in the third embodiment.

Fig. 14 is an explanatory drawing that explains the principle of position detection in the third embodiment.

Fig. 15 is an explanatory drawing that explains the principle of position detection in the third embodiment.

DETAILED DESCRIPTION OF INVENTION

Best Mode for Carrying Out the Invention

First Embodiment

The following provides an explanation of a position detection apparatus according to a first embodiment of the present invention with reference to the drawings. Fig. 1 is a block diagram showing the constitution of the present embodiment. Here, the position detection apparatus shown in Fig. 1 is explained in the form of that equipped on an autonomous travel robot that moves indoors. In this drawing, reference symbol 1 represents two cameras that capture an object present in the field of view in the direction of movement during movement by the robot. These cameras are installed at a prescribed interval, and their mutual fields of view are aligned. Reference symbol 2 represents ~~a distance~~ an image storage unit that respectively stores individual frames of images obtained by cameras 1, and is composed of two frames of image memory. Reference symbol 3 represents a distance image formation unit that forms distance images from two frames of images stored in image storage unit 2. Reference symbol 4 represents a distance image storage unit that stores the distance images formed in distance image formation unit 3. Reference symbol 5 represents a characteristic point extraction unit that extracts characteristic points from images stored in image storage unit 2 or distance image storage unit 4. Reference symbol 6 represents a position detection unit that detects self-position based on the results of characteristic point

stationary object (Step S13). On the other hand, in the case the above calculated difference is greater than threshold value A, position detection unit 6 judges the characteristic point used when calculating the relevant displacement vector da to be a moving object (Step S14). This processing is performed for all calculated displacement vectors da (Step S15) and as a result, a judgment is made as to whether a characteristic point is a stationary object or moving object for each characteristic point.

Next, position detection unit 6 extracts those characteristic points judged to be stationary objects for which certainty CA is the superordinate (Step S16). Here, certainty CA being superordinate refers to certainty CA being superordinate the smaller the value of CA. Those characteristic points extracted by this extraction processing are characteristic points of a previous image (time t) that form a pair with characteristic points of the input image (time t+1), and these characteristic points serve as the reference characteristic points for calculation of self-position.

Next, position detection unit 6 determines characteristic point distance from the correlating points between each of the extracted reference characteristic points and the distance image stored in distance image storage unit 4, and calculates the amount the robot moved from the time at which the previous image was acquired to the time at which the current image (input image) was acquired based on the amount of movement of that characteristic point and the relative position of the robot (Step S17). When the processing of Step S17 is completed and the position of the robot is determined, the program returns again to Step S1 and repeats the same processing on a characteristic point for which a correlation was previously obtained that has been stored in memory.

Here, an explanation is provided of the principle for calculating self-position with reference to Fig. 4. The coordinate system here is a coordinate system defined when the robot is in the initial state, and the forward direction of the robot is designated as the

each time from the amount of this displacement, thereby enabling self-position to be detected accurately. Although the explanation here has dealt with the example of performing tracking processing with two consecutive images, in order to improve reliability and precision, tracking may be performed by determining the history of movement of a characteristic point from two or more images and extracting stationary objects. therefrom

In this manner, in the case the position of a target characteristic point is known, the absolute position of the robot can be determined, and in the case it is unknown, robot position (x_{t+1},y_{t+1}) can be determined by determining the target position from the target relative position and robot position (x_t,y_t) at time t based on the amount of displacement of the position of that target at time t+1. In addition, in the case of having continuously tracked the same target for a continuous amount of time K, the position at time t+k can be similarly detected based on the amount of displacement of (x_{t+k},y_{t+k}) during time k.

Furthermore, distance image formation unit 3 shown in Fig. 1 may be replaced with radar and so forth using ultrasonic waves or electromagnetic waves. At this time, the measuring field of view of the radar is set to be the same as that of cameras 1 shown in Fig. 1. In addition, in the case of obtaining distance images using radar and so forth, only a single camera 1 should be provided for obtaining brightness images.

In addition, in the case the moving body is moving, characteristic points may move outside the frame as the moving body approaches a characteristic point, thereby preventing detection of position. Consequently, characteristic points for which the amount of movement is calculated are successively switched by performing the processing shown in Fig. 2 on all of a plurality of characteristic points. In this case, however, since the error in measured distance increases as the characteristic point moves away from the moving body s compared with the case of approaching the moving body,

objects U3 and U4, and adding the determined amount of movement to the relative coordinate values of point B (Step S29). In the case a known object is captured during the course of moving to point C, absolute self-position is determined based on that known object, and the error in relative position determined according to the amount of movement is reset.

In this manner, in the case of determining absolute self-position based on the position of an unknown object, although the error in relative position obtained from a distance image accumulates, in the case a known object is captured, since self-position can be determined from this known object, the cumulative error can be reset, thereby enabling accurate position detection.

Next, when again moving in the same area, in the case of moving to point A, since previously unknown objects U1 and U2 are now stored in internal memory as map position data and object data, they are used as known objects. In addition, this applies similarly to unknown objects U3 and U4. In addition, in the case a previously known object cannot be recognized to be present currently, since there is the possibility that the object is a moving object, processing may be added in which the possibility of that object being a moving object is stored in memory and removed from the detected objects.

However, since variations in distance data obtained from images may be large, there are cases in which it is difficult to determine the position of the robot by the method described above. Consequently, robot position may be calculated using a Kalman filter based on extracted reference characteristic points. By using this Kalman filter, robot position can be calculated while taking into consideration variations in distance data and so forth.

Here, an explanation is provided of the processing for calculating robot position

in the case of using a Kalman filter. The Kalman filter used here is an extended Kalman filter, and the its status equation is shown in Equation (1). Here, if the variables that express the status of the robot are represented with x, y, ϕ and T, and defined as:

$$\vec{P} = \begin{bmatrix} x_t \\ y_t \\ \phi_t \\ T_t \end{bmatrix}$$

then x_t and y_t are the x and y values on the x and y axes, ϕ_t is the angle of rotation about the z axis, and T_t is the distance when moving from time step t to time step (t+1).

$$\begin{bmatrix} x_{t+1} \\ y_{t+1} \\ \phi_{t+1} \\ T_{t+1} \end{bmatrix} = \begin{bmatrix} x_t + \Delta T_t \cos\phi \\ y_t + \Delta T_t \sin\phi \\ \phi_t \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \Delta\phi_t \\ \Delta T_t \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ v_\phi \\ \upsilon_T \end{bmatrix} \quad \ldots(1)$$

In Equation (1), the second term from the right is the amount of change in distance control at time t from movement control unit 7, while the third term represents the system noise associated with robot control at time t. The coordinate system used here

is the same as that of Fig. 5 4, while the meanings of each of the parameters that express the status of robot position are shown in Fig. 10.

In addition, Equation (2) is the observation equation of characteristic point a, while Equation (3) is the observation equation of characteristic point b. These equations indicate the relative measured values of characteristic points a and b as viewed from the robot. This measurement equation is produced geometrically based on the coordinate system shown in Fig. 5 4. The measured amount is expressed with three variables consisting of x, y and θ in the following manner:

If $\vec{\ell} = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix}$ is defined, then

$\vec{\ell}_1$ becomes

$$\begin{bmatrix} x_a \\ y_a \\ \theta_a \end{bmatrix} = \begin{bmatrix} (a_x - x_t)\cos(-\phi_t) - (a_y - y_t)\sin(-\phi_t) \\ (a_x - x_t)\sin(-\phi_t) + (a_y - y_t)\cos(-\phi_t) \\ \tan^{-1}\left(\frac{E_2}{E_1}\right) \end{bmatrix} + \begin{bmatrix} \omega_{ax} \\ \omega_{ay} \\ \omega_{a\theta} \end{bmatrix} \quad \ldots(2)$$

and $\vec{\ell}_2$ becomes

$$\begin{bmatrix} x_b \\ y_b \\ \theta_b \end{bmatrix} = \begin{bmatrix} (b_x - x_t)\cos(-\phi_t) - (b_y - y_t)\sin(-\phi_t) \\ (b_x - x_t)\sin(-\phi_t) + (b_y - y_t)\cos(-\phi_t) \\ \tan^{-1}\left(\dfrac{E_4}{E_3}\right) \end{bmatrix} + \begin{bmatrix} \omega_{bx} \\ \omega_{by} \\ \omega_{b\theta} \end{bmatrix} \quad \ldots(3)$$

Furthermore, the following are also true:

$$E_1 = (a_x - x_t)\cos(-\phi_t) - (a_y - y_t)\sin(-\phi_t),$$
$$E_2 = (a_x - x_t)\sin(-\phi_t) + (a_y - y_t)\cos(-\phi_t),$$
$$E_3 = (b_x - x_t)\cos(-\phi_t) - (b_y - y_t)\sin(-\phi_t),$$
$$E_4 = (b_x - x_t)\sin(-\phi_t) + (b_y - y_t)\cos(-\phi_t),$$

Here, the second term on the right side in Equations (2) and (3) represents noise.

The above Equations (1) through (3) are used in the processing of Steps S25 and S29 shown in Fig. 2 6. By performing arithmetic operations on these equations each time an image is acquired, robot angle of rotation ϕ_{t+1} and robot position (x_{t+1}, y_{t+1}) can be determined. By using this extended Kalman filter, robot position can be detected more accurately since both system noise and measurement noise are taken into consideration as compared with calculating geometrically as described above. In addition, when using a Kalman filter, although not specifically stated in the judgment of Step S28, the covariance of observed values relative to characteristic points that converges within the Kalman filter can be used as the variance values of those characteristic points.

W are correlated with position M and stored in object data storage unit 8. Since the characteristic point groups here do not allow identification of their respective relative positions due to occlusion and so forth, stored positions are correlated for all characteristic points.

Fig. 14 indicates the example of there being 9 positions at which characteristic point groups are stored in memory (M1 through M9), these positions being preset at positions over which the robot is likely to pass. If characteristic point groups extracted from image captured with a camera facing in the direction of forward direction F→ of the robot from each preset position M1 through M9 are designated as W1 through W9, each position (referred to as a characteristic point acquisition position) M1 through M9 and characteristic point groups W1 through W9 are correlated into respective pairs which are then stored in advance in object data storage unit 8. When the robot is passing over an unknown position, the correlation between the characteristic point groups extracted from the image captured with the camera facing in the direction of forward direction F→ and pre-stored characteristic point groups W1 through W9 is determined, and characteristic point group Wn (where n is any of 1 through 9) having the highest correlation is judged to be the position over which the robot is passing, and the characteristic point acquisition position Mn (where n is any of 1 through 9) that forms a pair with this characteristic point group Wn becomes the self-position. For example, when characteristic point group W4 and a characteristic point group extracted from an image captured with the camera exhibit the closest correlation, position M4 at which this characteristic point group W4 was acquired is determined to be the self-position.

Next, an explanation is provided of the specific procedure for determining

S42 through S48 consists of determining the certainty for all of the characteristic points that compose the characteristic point groups extracted from the input image as well as all of the characteristic points stored in object data storage unit 8. Furthermore, in the processing of Steps S44 through S50, the processing load can be reduced by determine certainty after selecting those characteristic points in close proximity to the image pixels.

Next, self-position determination unit 10 selects the characteristic point group for which the sum S of certainty CA determined in Step 48 is large st (Step S52). Self-position is then determined by reading the characteristic point acquisition position that forms a pair with the selected characteristic point group from object data storage unit 8 (Step S53) followed by output of that position as self-position data.

In addition, as shown in Fig. 15, two left and right cameras that compose a stereo camera of the robot may be used to compare a pre-stored characteristic point group W for each camera and arithmetically determine correlation. When this is done, self-position can be determined according to the difference in the magnitudes of the degree of correlation of the camera images relative to the same characteristic point group W. Namely, the direction of offset to the left and right of position M can be detected from the difference in correlation values detected with each camera relative to position M corresponding to characteristic point group W. Consequently, since the number in the left and right directions of position M at which the characteristic point group is obtained can be reduced, the bother associated with capturing an image in advance can be reduced considerably. In addition, in the case there are two or more cameras that compose a stereo camera, they should be used by selecting cameras arranged in the left and right directions.

In this manner, since characteristic point groups within the movable range of a robot and positions at which those characteristic point groups were acquired are

pre-stored in the robot, a characteristic point group having a high correlation with characteristic point groups extracted from an image obtained when the robot takes an action is selected from the characteristic point groups stored in memory, and the position at which that selected characteristic point group was acquired is taken to be self-position, so that self-position can be detected easily in cases such as when a robot acts within a predetermined room.

Although the above Figs. 13 and 14 were explained assuming a single direction for the direction of image capturing at each position M1 through M9, if images in a plurality of directions are captured at each position, characteristic point groups are extracted for all resulting images, and those characteristic point groups are stored in object data storage unit 8, self-position can be detected by the same processing even if the forward direction of the robot differs at each position. In addition, the robot may also be made to extract characteristic point groups from enlarged or reduced images by using a zoom function of the camera equipped on the robot itself. If this is done, it becomes easier to obtain a correlation in a case such as when the robot is positioned between positions M2 and M5 shown in Fig. 14. Moreover, the robot may also be made to extract characteristic point groups from images obtained in a state in which a head unit equipped with a camera swings horizontally and vertically. When this is done, it becomes easy to obtain a correlation between characteristic points even in cases in which the robot is acting in a direction different from the forward direction when it acquired a stored characteristic point group.

In addition, the position detection processing previously described in the three embodiments may be suitably combined corresponding to the environment in which the robot moves, and self-position may be detected by selecting the necessary processing.

In addition, a program for realizing the processing shown in Figs. 2, 6 and 12 may

determined from the amount of this displacement, whereby ~~the~~ the present invention offers the advantage of being able to accurately detect self-position. In addition, since extraction of the stationary object can be performed independently, the constitution can be simplified since it is not necessary to provide a map and so forth in which the positions of stationary objects have been defined in advance. Moreover, since it is not necessary to provide a map such as road map data, in addition to it being possible to simplify the constitution, since the advantage is offered in which it becomes possible to move to an unknown location and eliminate restrictions on the range of action of a moving object, the present invention is particularly suited to a humanoid robot that moves by the use of legs.

In addition, according to the present invention, since a position detection device is provided that detects self-position by substituting self-movement control and the observed amount of the above reference point into an extended Kalman filter, the present invention offers the advantage of being able to detect self-position more accurately.

In addition, according to the present invention, since pre-stored object data and extracted characteristic points are compared and characteristic points having a high degree of correlation are treated as known characteristic points and used as reference characteristic points for calculating self-position, the present invention offers the advantage of being able to detect self-position more accurately.

In addition, according to the present invention, since object data is updated by determining the correlation between unknown characteristic points and known characteristic points in an image in which characteristic points treated as being known are present, and said unknown characteristic points are then used as known characteristic points and stored in memory, the present invention offers the advantage of enabling updating of map data and object data to be performed automatically.

[0115] ¶ Although there have been described what are the present objects of the invention, it will be understood that changes and modifications may be made thereto without departing from the gist, spirit or essence of the invention. The scope of the invention is indicated by the appended claims.

ABSTRACT OF THE DISCLOSURE

The object of the present invention is to provide a position detection apparatus that is able to easily detect self-position during autonomous movement by a humanoid robot that moves by the use of legs or automobile.

The present invention discloses ~~a~~ A position detection apparatus that detects the position of a moving object, ~~said~~ the position detection apparatus ~~being provided with~~ comprised a brightness image acquisition device that acquires a brightness image of the forward field of view of the moving object, a distance image acquisition device having the same field of view as the brightness image acquisition device that acquires a distance image simultaneous to acquisition of a brightness image by the brightness image acquisition device, a characteristic point extraction device that extracts respective characteristic points from the brightness images of at least two consecutive frames, and a reference characteristic point selection device that calculates the amount of displacement of a position between two frames of a characteristic point extracted by the characteristic point extraction device based on a distance image, and selects a reference characteristic point for calculating self-position according to said amount of displacement.